

Sec (6)

Semiconductors

- ↳ ① Elemental Semiconductors
- ↳ ② Binary (Compound Semiconductors)
- ↳ ③ Ternary Compound & Quaternary Compounds (Alloy Semiconductors)

1] Elemental Semiconductors

↳ any element from Group IV in periodic table

Ex: Si, Ge, Sn

عدد الالكترونات في مستوى الطاقة الاخير بـ ④

2] Binary Semiconductors :

1] Contains element from group III
⊕ element from Group V

Ex: GaAs, AlP

OR

2] Element from Group II + element from Group VI

Ex: CdTe (Cadmium Telluride)

↳ used in photo voltaic solar cell

Common optoelectronic Materials Direct Band Gap

Application
↳ optical source

Material	Band Gap
GaAs	1.42
InP	1.35
InSb	0.17
InAs	0.36
GaN	3.39

Common optoelectronic Materials (Indirect Band Gap)

Application of Indirect Band Gap Material
is ① Solar cell
② photo detector (sensors)

Material	Band Gap
Ge	0.66
Si	1.12
AlAs	2.16
GaP	2.26
SiC	2.42

Silicon Carbide

used in humidity detectors

Note Depend on Band Gap wavelength (Cutoff wavelength)
we decide the application

$$\hookrightarrow \text{eg } E = hf \rightsquigarrow E_g = \frac{hc}{\lambda_g} \Rightarrow \lambda_g = \frac{hc}{E_g}$$

$$\text{eg } \lambda_g (\mu\text{m}) = \frac{1.24}{E_g (\text{eV})}$$

Ex 1 Calculate cut-off wavelength for GaAs?

Sol

$$\lambda_g = \frac{hc}{E_g} = \frac{1.24}{1.42} = 0.88 \mu m$$

من الجدول اعرف قيمه E_g لـ GaAs

2 Calculate Cut-off wavelength for SiC?

Sol

$$E_{g|SiC} = 2.42 \text{ eV}$$

$$\lambda_g = \frac{1.24}{2.42} = 500 \text{ nm} \rightarrow \text{Visible light}$$

إذا كل Material ممكن احد هي Indirect or Direct ← و حسب كده افتار
Application الي ممكن اشتغل به.

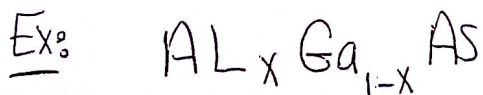
لكن لو عايناه اعمل Modification لـ Band Gap ← يعني احوط من Direct و Indirect
او العكس ← هنا تأثر فائده الـ

Alloy
Semiconductors

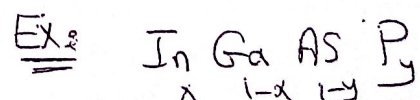
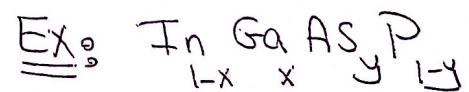
3 Alloy Semiconductor (Ternary and Quaternary)

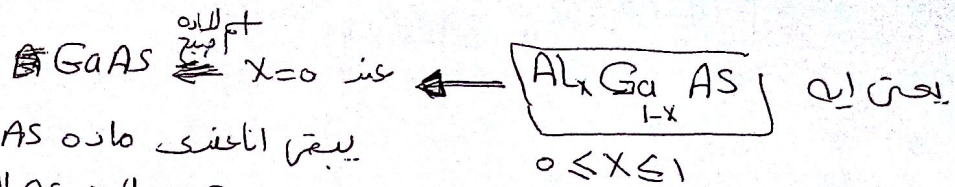
Two elements
From Group (3)

+ one element
From Group (5)



Two elements from Group
(3) + Two element from
Group (5)





- يبقى انا عنى مادة GaAs
- ال Ga من المجموعة ال (3)
 - وال As من المجموعة ال (5)
 - وال Al من المجموعة ال (3)

لو استبدلت مجموعة ذرات من ال Ga
 بمجموعة من ال (Al) كده انا عنى Alloy material
 عدد الذرات اللى استبدلتهم انا عنى x من العدد الكلي

يعنى ممكن اقول ان ال $Al_x Ga_{1-x} As \leftarrow$ المادة الاصلية هي GaAs
 Substrate $\Rightarrow$ ال GaAs
 و استبدلت x-Fraction من ال Ga بـ (Al)

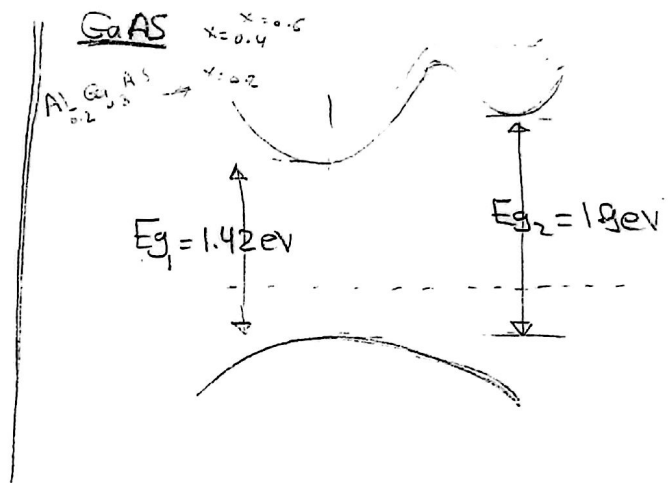
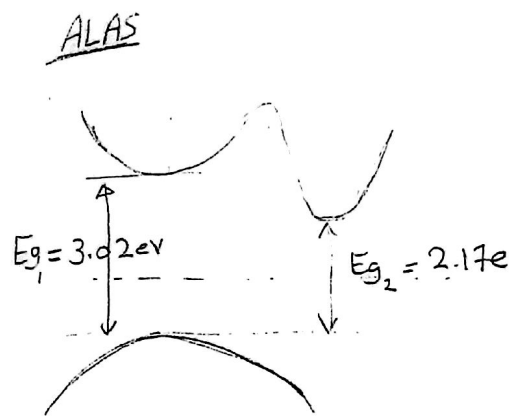
نفس الكلام مع ال $In_x Ga_{1-x} As_y P_{1-y}$

المادة الاصلية هي GaAs $\rightarrow$ Substrate

واستبدلت x-Fraction من ال (Ga) بـ (In) كائنهم من نفس المجموعة

واستبدلت y-Fraction من ال As بـ (P)

بالنسبة لـ $InP \leftarrow$ ال $In_x Ga_{1-x} As_y P_{1-y}$ $\leftarrow$ Substrate



→ في الجدول السابق لأنواع ال direct & Indirect

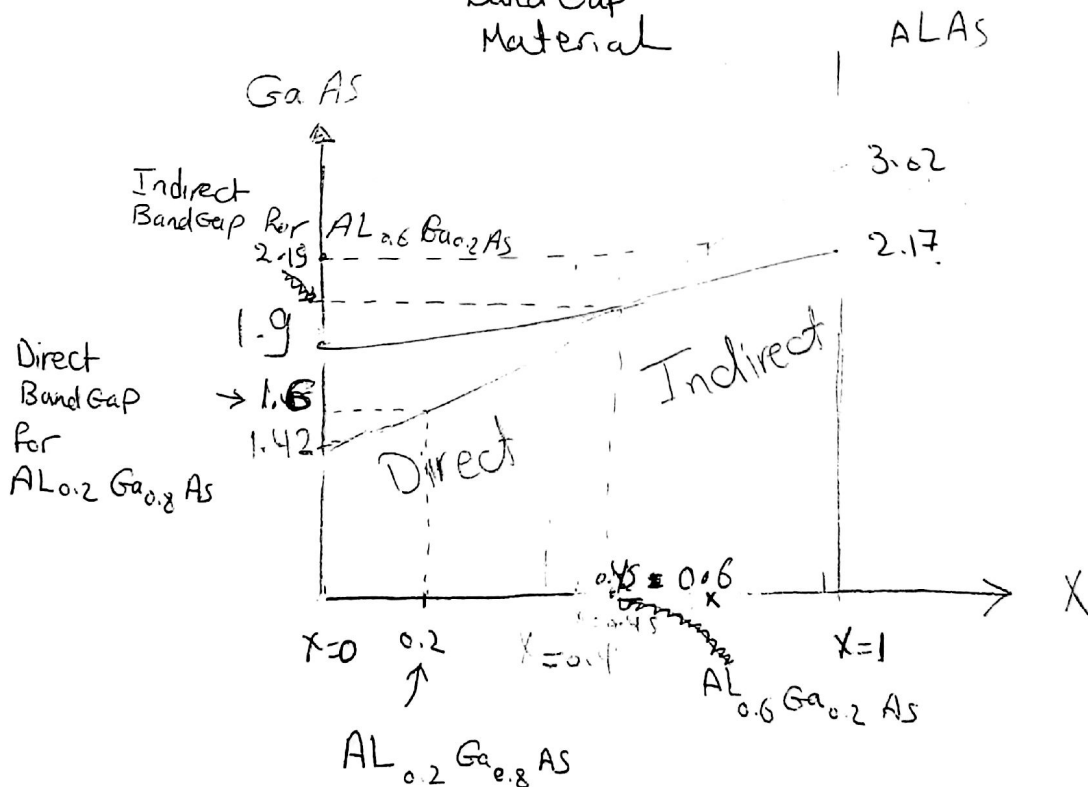
تم تصنيف GaAs على أنه Direct Material

لأنه عند E_{g1} & E_{g2}

→ لأنه يتم تصنيف حسب ال E_g الأقل

فأقل E_g لـ GaAs مباشر ال Direct → لأنه يُصنف على أنه Direct Bandgap Material

→ بينما ال ALAS → يُصنف على أنه Indirect Band Gap Material



Note

→ To determine the direct Band Gap Value (E_g)
for Alloy material ?

if $x < 0.45$

$$E_g = 1.424 + 1.247x$$

Ex: $(Al_{0.2}Ga_{0.8}As)$

$$E_g = 1.424 + (1.247 \times 0.2) = 1.6$$

if $x > 0.45$ " Indirect BandGap

$$E_g = 1.424 + 1.247x + 1.147(x - 0.45)^2$$

Ex: $(Al_{0.6}Ga_{0.4}As)$

$$\begin{aligned} E_g &= 1.424 + (1.247 \times 0.6) + (1.147(0.6 - 0.45)^2) \\ &= 2.13 \end{aligned}$$

Q3 Complete with suitable words

1. GaAs is classified as Binary (Compound) semiconductor.
2. Si is classified as Elemental semiconductor.
3. The material $Al_x Ga_{1-x} As$ is grown over GaAs substrate.
4. In $1-x Ga_x As_y P_{1-y}$ is grown over InP substrate.
5. For $Al_x Ga_{1-x} As$, at $x < 0.45$, the material is considered as direct band gap.
6. The cut off wavelength of Si material is $\lambda_g = \frac{1.24}{1.12} = 1.107 \mu m = 1107 nm$
 $E_g = 1.12 eV$

Indirect Band Gap

photo detector

Direct Band Gap

optical

Source

7. Si can be used as photo detector while GaAs can be used as optical Source.
8. As the band gap energy decrease the intrinsic carrier concentration increases. $n_i = \sqrt{N_c N_v} e^{-E_g/2kT}$
9. As the effective mass increases the intrinsic carrier concentration for bulk material increases.
10. The direct band gap energy of $Al_{0.2} Ga_{0.8} As$ is equal to 1.6.
11. The indirect band gap energy of $Al_{0.6} Ga_{0.4} As$ is equal to 2.13 epitaxy.
12. The term PIC stands for photonic integrated circuits and the fabrication of the PICs depends on process.

Q(5)

Q5. Make a comparison between

- a) Alloying and Doping
- b) Homojunctions and Heterojunctions
- c) Anisotype heterojunction and Isotype heterojunction (compare & give examples)
- d) Straddling, Staggered and Broken-gap heterojunctions (use schematics diagrams)
- e) Radiative transition and Non radiative transition
- f) Materials: $Al_{0.2} Ga_{0.8} As$ and $Al_{0.6} Ga_{0.4} As$ (bandgap- type- application)

Alloying

1. Substitutional element from the same group
 Ex: $Al_x Ga_{1-x} As / GaAs$

2. Reason for use Alloying
 ↳ To change "Modify" Band Gap

3. Atoms Concentration = $10^{22} cm^{-3}$

Doping

1. Substitutional element from adjacent group

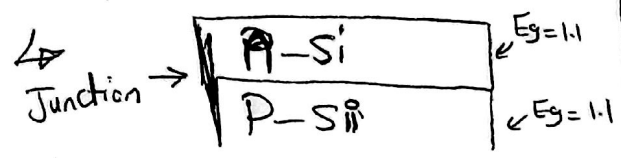
Ex: SiP $\Rightarrow Si \rightarrow \text{IV} \& P \rightarrow \text{V}$

2. Reason for use Doping:
 ↳ To increase Conductivity

3. Atoms Concentration = $10^{12} - 10^{19} cm^{-3}$

b

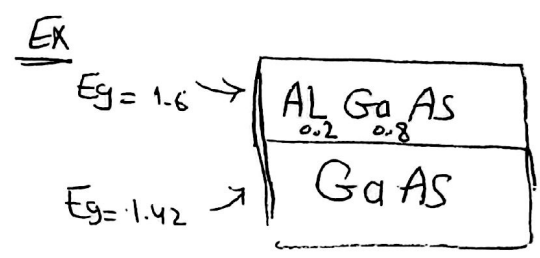
Homo Junctions



→ Junction between 2 Semiconductor materials with same E_g
 ~ (Si) $C_{crystal} \log_2$

Hetero Junctions

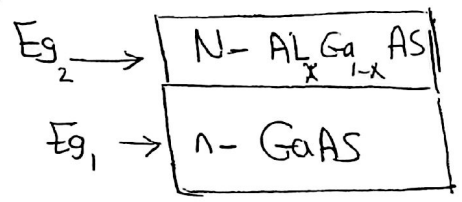
→ Junction between 2-Semiconductor materials with different E_g .



c Anisotype hetero Junction, Isotype hetero Junction (Compare & give examples)

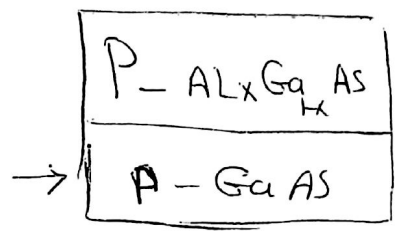
Isotype

① N_n (type)



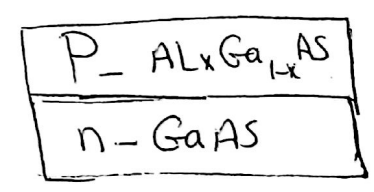
$$E_{g1} < E_{g2}$$

② P_p type

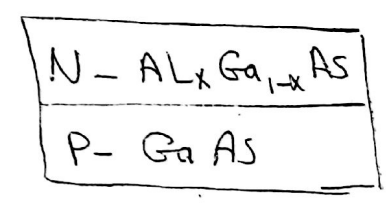


Anisotype

① P_n



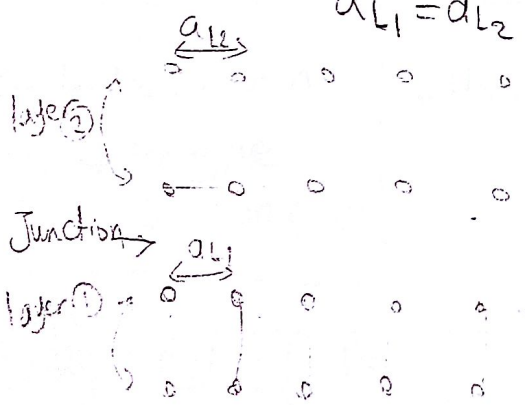
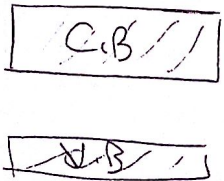
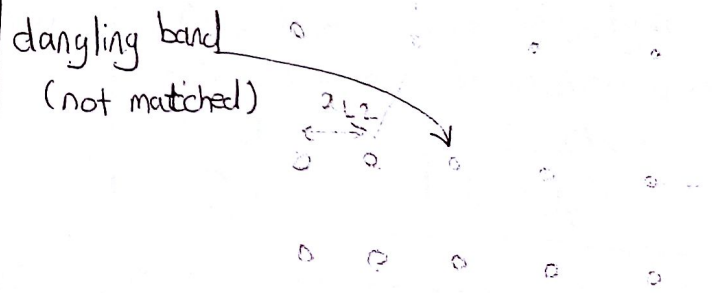
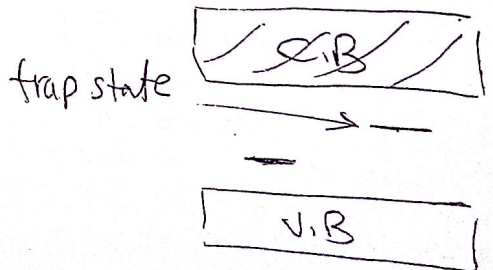
② N_p



d

Straddling Alignment		Staggered Alignment		Broken Band Gap Alignment	
①	②	①	②	①	②
E_{c1}	E_{c2}	E_{c1}	E_{c2}	E_{c1}	E_{c2}
E_{v1}	E_{v2}	E_{v1}	E_{v2}	E_{v1}	E_{v2}

☐ Radiative and Non Radiative transition •

Radiative Transition	Non-Radiative Transition
↳ Epitaxial layers must be lattice matched $a_{L1} = a_{L2}$  ↳ There is no trap state in Band diagram 	↳ Epitaxial layers have lattice mis match. $a_{L1} \neq a_{L2}$  ↳ There is trap state in Band diagram 

F

	$Al_{0.2}Ga_{0.8}As$	$Al_{0.6}Ga_{0.4}As$
<u>Band Gap</u>	$x < 0.45$ $\hookrightarrow E_g = 1.42 + 1.247x$ $= 1.6$	$x > 0.45$ $\hookrightarrow E_g = 2.13$
<u>Type</u>	$\hookrightarrow$ Direct Band Gap Alloy material	$\hookrightarrow$ Indirect Band Gap Alloy Material
<u>Application</u>	$\hookrightarrow$ Optical Source	$\hookrightarrow$ Photo detector (Optical Sensor) $\hookrightarrow$ Solar cell

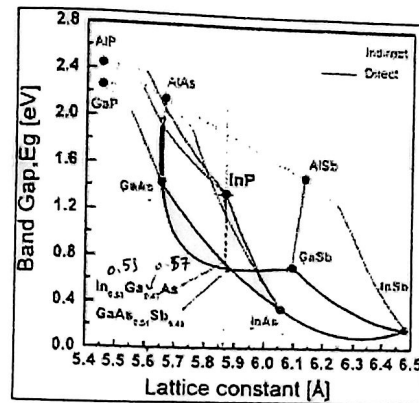
Compare

- g) Structures: ① $N-GaAs / N-Al_{0.2}Ga_{0.8}As$ ② $N-Si / P-Si$ ③ $N-GaAs / P-Al_{0.6}Ga_{0.4}As$ and ④ $GaAs / N-Al_{0.6}Ga_{0.4}As$
h) Heterojunction labels nN, Pp, Np and Pn

①	②	③	④
$N-Al_{0.2}Ga_{0.8}As$ $N-GaAs$	$P-Si$ $N-Si$	$P-Al_{0.6}Ga_{0.4}As$ $N-GaAs$	$N-Al_{0.6}Ga_{0.4}As$ $P-GaAs$
$\hookrightarrow$ Heterojunction $\hookrightarrow$ isotype Junction (nN)	$\hookrightarrow$ Homojunction	$\hookrightarrow$ Anisotype heterostructure Junction (P_n)	$\hookrightarrow$ Anisotype heterostructure Junction (N_p)

nN	Pp	Np	Pn
$\hookrightarrow$ isotype heterojunction	$\hookrightarrow$ Isotype heterojunction	$\hookrightarrow$ Anisotype heterojunction	$\hookrightarrow$ Anisotype heterojunction
$N-Al_{0.2}Ga_{0.8}As$ $N-Al_{0.6}Ga_{0.4}As$	$P-Al_{0.6}Ga_{0.4}As$ $P-GaAs$	$N-Al_{0.2}Ga_{0.8}As$ $P-GaAs$	$P-Al_xGa_{1-x}As$ $N-GaAs$

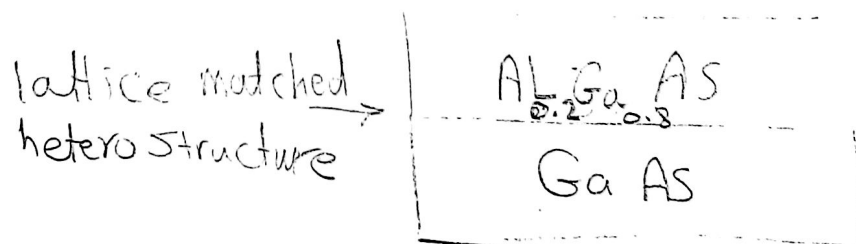
Q7. The following diagram shows the relation between the energy bandgap and lattice spacing for different semiconductor materials; based on the given diagram suggest alloys for designing optical sources and optical detectors. Give reasons for your suggestions.



→ optical source → Radiative transition + Direct Band Gap
 → layers must be matched
 $a_1 = a_2$

→ ايجت عن Material 2 على خط a_1 نفس واه
 بحيث يكون الخط منحنى " — " ليس " ---- "
 ↑
 direct

$$a_1 = a_2 = 5.61 \text{ \AA}$$



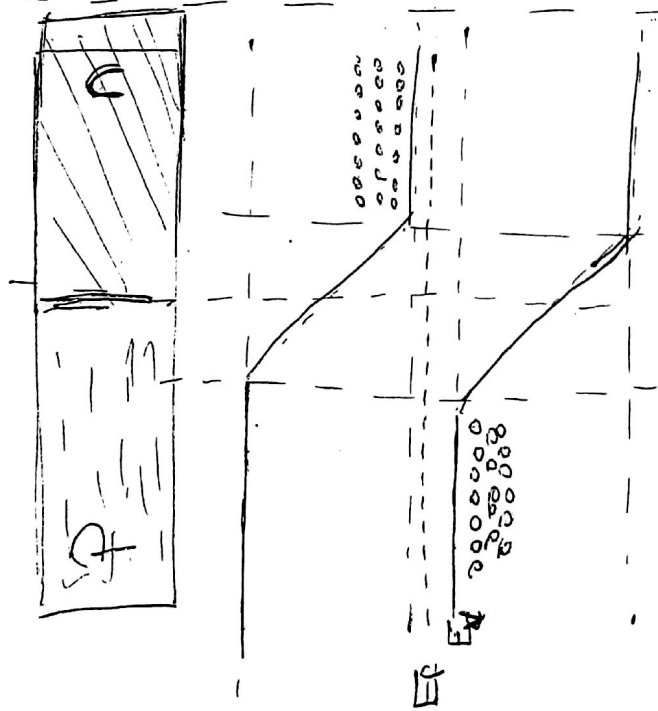
optical source suggestion

$\hookrightarrow$ optimal solution $\rightarrow$ Reduktion transform
 in die 'normale' Form
 - Simplex-Prüfung

$$z_{\text{opt}} = 12 = 4 \cdot 3 = 12$$

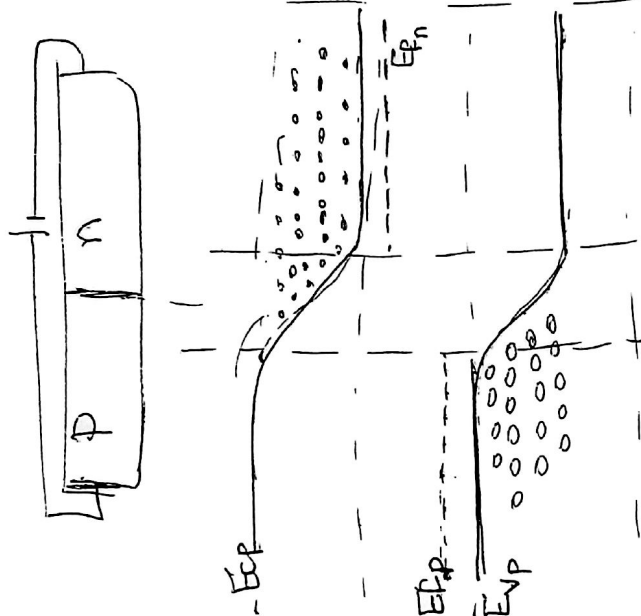
$$\text{für } I_{0.5} = 1.5 \rightarrow 1.5 \cdot 8 = 12$$

$$I_{0.5} = 3.47 \text{ bis}$$



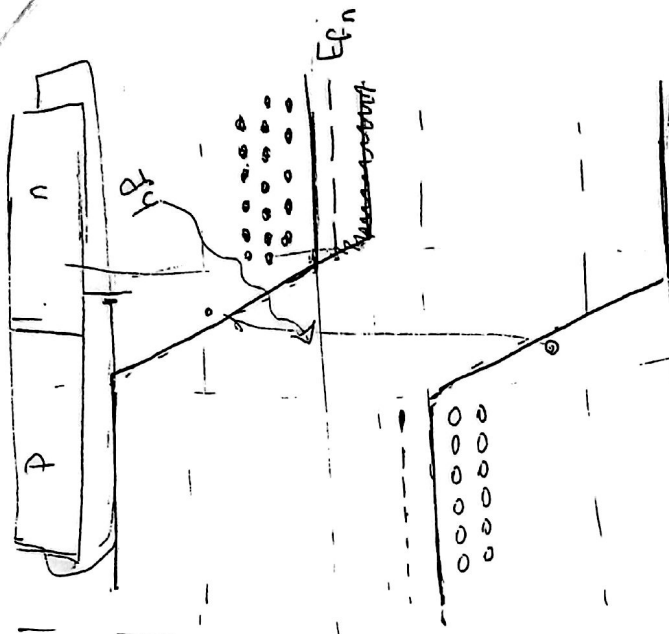
depletion
Region

PN-Junction at
equilibrium



PN-Junction
F.B

Application
→ optical Source



PN-Junction
R.B

→ Application
optical ~~photo~~ detector

G] Conductivity

$$\sigma = n * \mu_e * q + p * \mu_v * q$$

↳ $\mu_e \rightarrow$ Mobility of Carriers in C.B
 $\mu_v \rightarrow$ " " " " in v.B

$\frac{n, p}{L} \rightarrow$ For intrinsic material

$$n_i = n = p = \sqrt{N_c \cdot N_v} e^{-E_g/2KT}$$

↳ n-type $n_i^2 = n \cdot p \Rightarrow n = N_D \rightarrow p = \frac{n_i^2}{N_D}$

↳ p-type $n_i^2 = n \cdot p \Rightarrow p = N_A \Rightarrow n = \frac{n_i^2}{N_A}$